

61015

DRAFT

Dimict Breccia
1789 grams

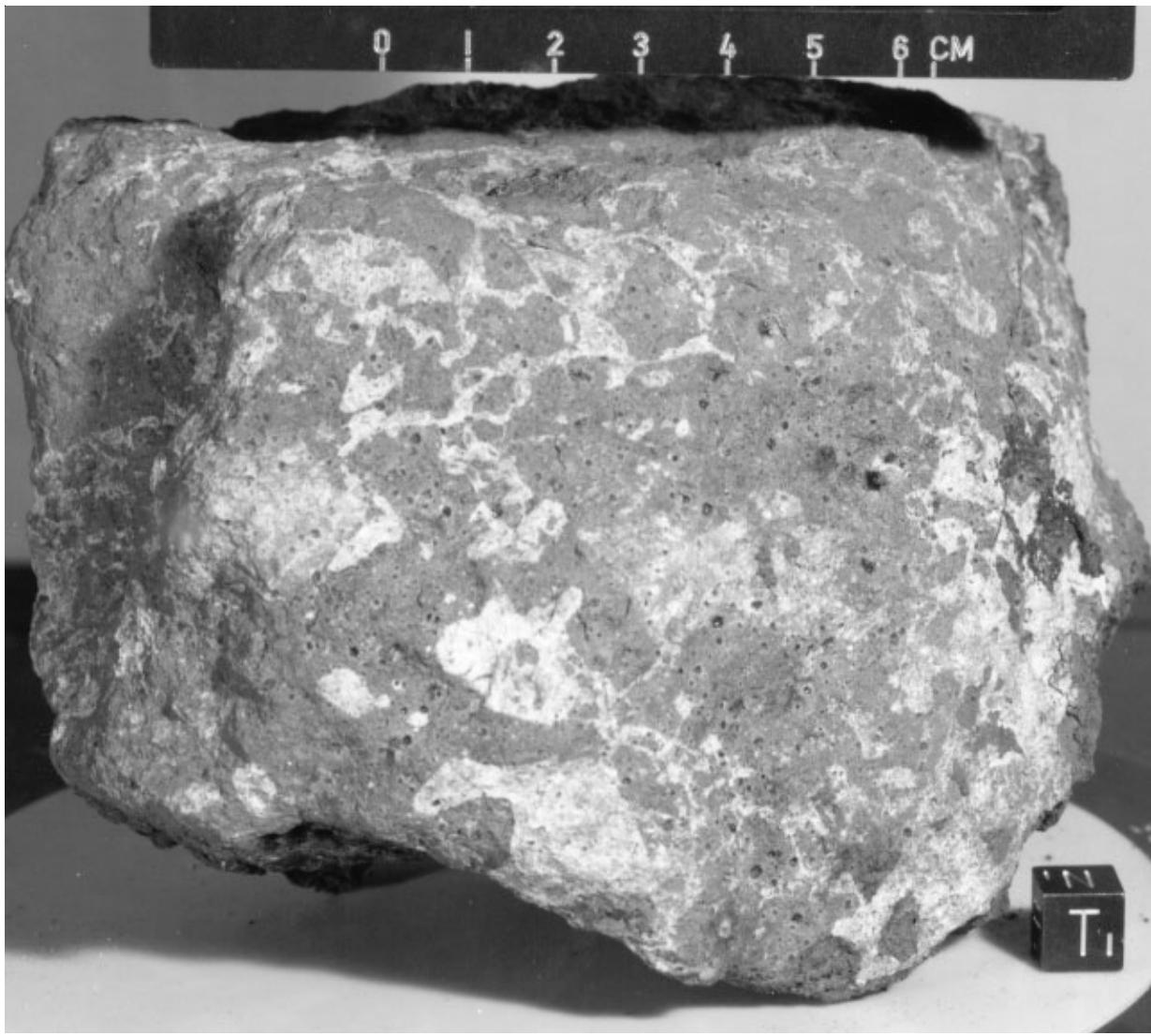


Figure 1: Photo of 61015. NASA #S72-37758. Scale and cube in cm. Note the zap pits on the T1 surface and the residual black glass coating on the sides.

Introduction

Breccia 61015 is one of the best examples of the Apollo 16 dimict breccias (figures 1 and 2). These breccias consist of anorthositic material and impact melt rock with high Al content.

Breccia 61015 was collected from on top of the soil about 10m south of Plum Crater. It was coated with black glass and is thought to be ejecta from South Ray Crater. Micrometeorite bombardment apparently eroded the original glass coating on the top surface.

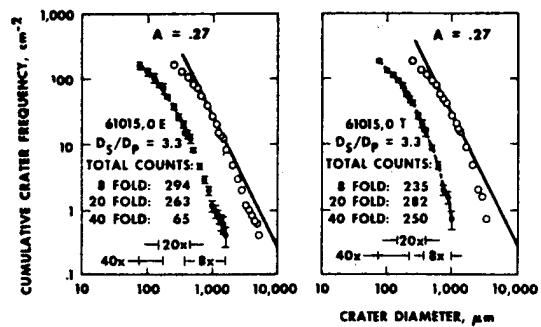


Figure 2: Micrometeorite count on top and side of 61015 (from Neukum et al. 1973).



Figure 3: Sawn surface of 61015,0 showing white anorthosite invaded by dark, recrystallized melt. Sample is 10 cm across. NASA # S83-36149.

Petrography

The petrology of breccia 61015 is fully explained by James et al. (1984). It consists of roughly about $\frac{3}{4}$ impact melt and $\frac{1}{4}$ anorthosite lithologies. The impact melt seems to have intruded the anorthosite lithology (McGee et al. 1979) and has recrystallized (figure 3).

The plagioclase in the anorthositic material is extremely fractured and deformed by impact processes. Plagioclase has patchy and undulatory extinction, contains healed shears, and locally contains patches of narrow shock-induced twin lamellae (James et al.

1984). Pyroxenes within the anorthosite show undulatory extinction and very locally augite contains shock-induced twinning. Fragments of single crystals of plagioclase are as much as 3.4 mm across and some pyroxenes are up to 0.9 mm, indicating the original coarse grain size of the parental rock. Based on mineral composition, the parental rock was ferroan anorthosite (figure 6 and 8).

Most of the melt-rock has a fine-grained intersertal texture (figures 4, 5) typical of other dimict breccias from Apollo 16 (James et al. 1984). It largely consists of a mat of randomly oriented plagioclase laths (~ 50

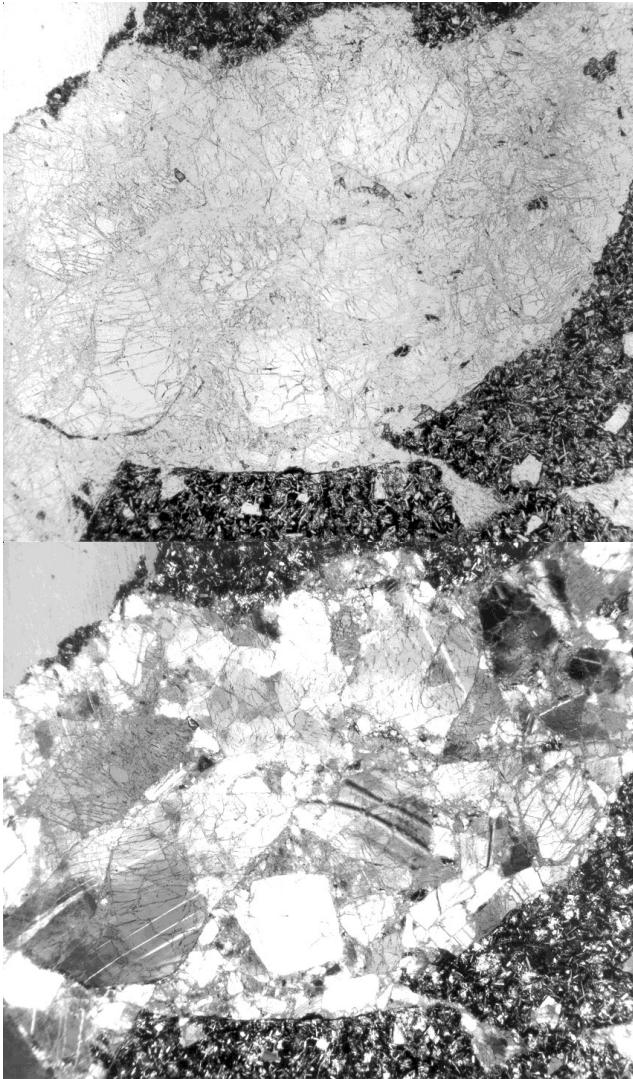


Figure 4: Photomicrographs of thin section 61015, 5 showing anorthosite clast in transmitted and partially crossed polarized light. Field of view about 5 mm. NASA S72-45692 and 45688.

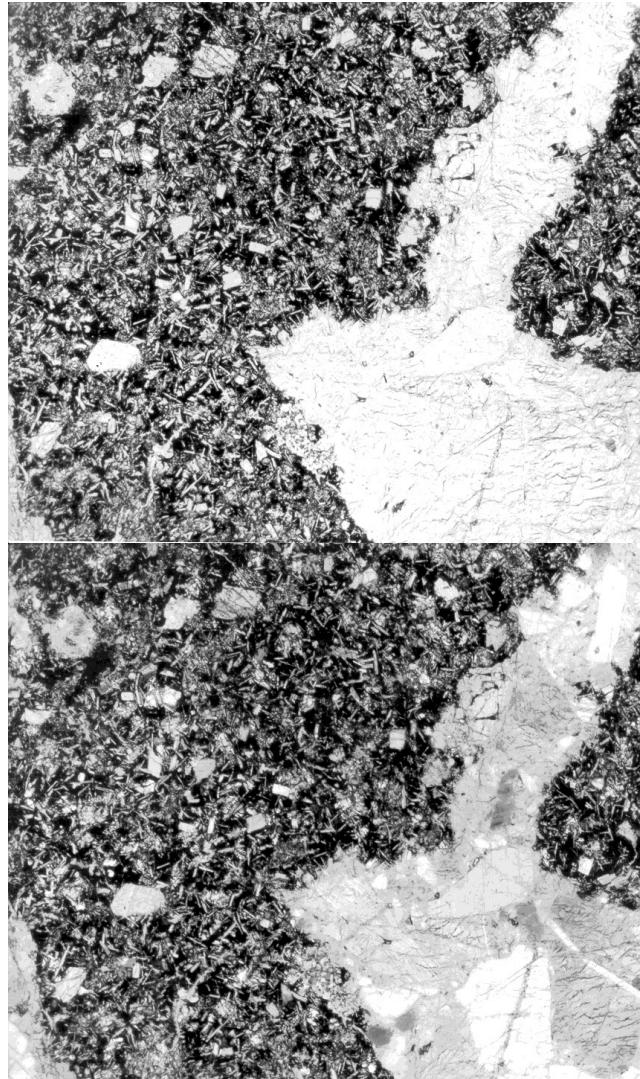


Figure 5: Photomicrographs of thin section of 61015 showing recrystallized melt-rock and portion of included anorthosite. Field of view about 5 mm. NASA S72-45703 and 45699.

microns), equant grains of olivine (50-100 microns) subophitically enclosing the plagioclase, and microcrystalline dark brown mesostasis filling the intersticies. Included within this mat are rare large olivine grains, small pink spinels and globules of intergrown iron-schreibersite-troilite.

Rare, small, clasts of unusual rocks are also reported as clasts in the melt-rock by James et al. (1984). A rounded clast of granulitic spinel troctolite, about 2.1 mm across, consists of 70% olivine (Fo91), 20% plagioclase (An95), 5% pink spinel, 5-10% intergrowth. Another unusual clast of “feldspathic, fragment-laden, melt rock” was described.

Mineralogical Mode of Anorthosite in 61015

	James et al. 1984
Plagioclase	96 %
Pyroxene	3-4
Ilmenite	tr.
Chromite	tr.
Olivine	tr.
Silica	tr.
Troilite	tr.
Iron	tr.

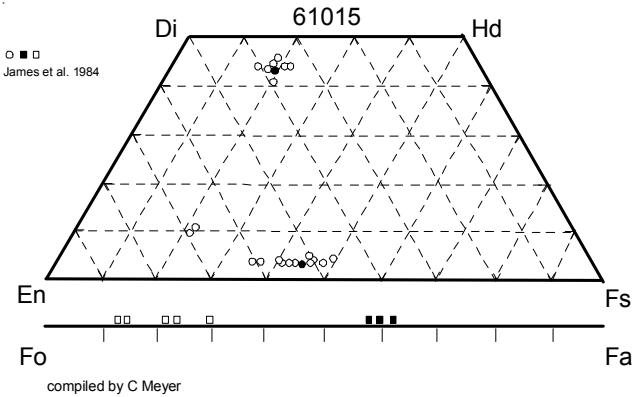


Figure 6: Olivine and pyroxene composition in anorthositic portion of 61015 (see James et al. 1984 for details).

James et al. (1984), See et al. (1986) and Morris et al. (1986) studied the glass coating on 61015 and other rocks. The glass coating on 61015 is highly variable in color, texture and extent of crystallization. Glass splash is colorless, virtually free of inclusions and roughly follows the contours of the broken rock surface. Ropy glass on the bottom surface is almost entirely crystallized to an aggregate of brown spherulitic patches. Vesicles are sparse. Glass veins and “patches” are also reported within 61015 (James et al. 1984).

Neukum et al. (1973) reported identical crater count on the top (T) and side (E) of 61015 (figure 2).

Mineralogy

Olivine: Olivine inclusions in plagioclase in the anorthositic portion of 61015 is Fe-rich (Fo_{40}), while olivine found in the melt-rock ranges from Fo_{71-95} . A single large olivine (360 microns) was found unzoned Fo_{91} .

Pyroxene: Both orthopyroxene and augite with a range of Fe content are found in the anorthositic portion (Figure 7).

Plagioclase: Plagioclase in the anorthositic portion averages $Or_{0.025}Ab_{3.8}An_{96.1}$ while plagioclase in the melt rock averages $Or_{0.2}Ab_{5.8}An_{94}$.

Pink Spinel: A single large grain of pink Mg-Al spinel (80 microns) was reported by James et al.

Opaques: Analyses of both ilmenite and chromite are given in James et al.

Glass: James et al., See et al. and Morris et al. analyzed the glass.

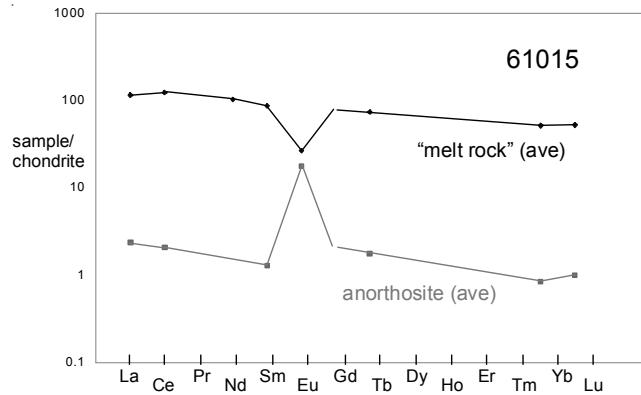


Figure 7: Normalized rare-earth-element diagram for the two main lithologies from 61015 (data averaged from James et al. 1984).

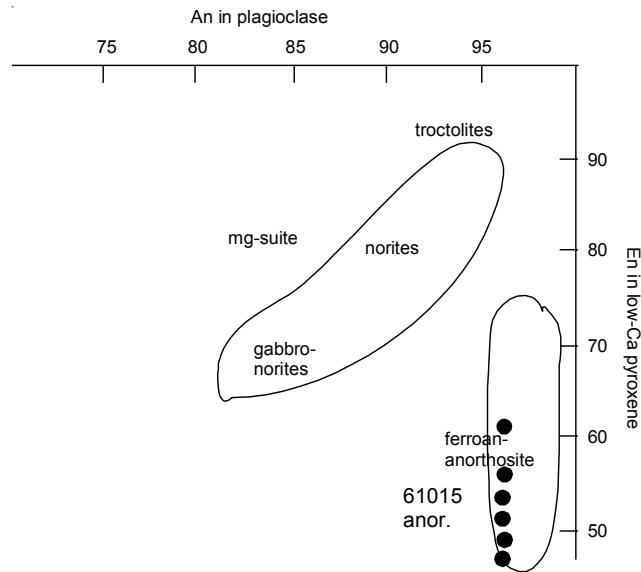


Figure 8: Composition of plagioclase and orthopyroxene in anorthositic portion of 61015. (from James et al. 1984).

Chemistry

Averages of the composition of several clasts are given in table 1. The VHA melt rock has high REE, while the anorthositic portion has a large Eu anomaly and extremely low REE (figure 7). Glass compositions are intermediate. The subsamples of VHA melt-rock have very high meteoritic siderophiles, including high Ni and Ir.

Radiogenic age dating

There is no reported age data for 61015.

Table 1a. Chemical composition of 61015.

reference	Palme 78		Christian 76			James 84 glass coat			Ebihara 92 anor. melt		Morris 86 glass
weight	light	dark	(b)	45.23	45.8	(b)					45.07
SiO ₂ %	45.5	44.8	(b)	0.45	0.79	(b)	0.33	0.23	0.14	(a)	0.25
TiO ₂	0.27	0.62	(b)	26.87	22.09	(b)	28.1	28.1	28.1	(a)	27.59
Al ₂ O ₃	32.9	24.5	(b)	4.42	6.4	(b)	5.14	4.79	4.48	(a)	5.06
FeO	2.95	6.69	(b)	0.07	0.1	(b)					
MnO	0.033	0.08	(b)								
MgO	2.9	8.9	(b)	6.61	10.5	(b)	7.01	5.85	5.47	(a)	6.44
CaO	17.8	13.6	(b)	15.5	13.36	(b)	14.9	15.7	16	(a)	15.01
Na ₂ O	0.47	0.49	(b)	0.42	0.47	(b)	0.465	0.468	0.486	(a)	0.62
K ₂ O	0.048	0.13	(b)	0.09	0.21	(b)					0.49
P ₂ O ₅	0.087	0.195	(b)	0.09	0.19	(b)					0.09
S %	0.05	0.215	(b)								
<i>sum</i>											
Sc ppm	3.85	8.85	(a)	<10	<10	(b)	4.89	4.06	4.04	(a)	4.72
V						14	20	16	(a)		
Cr	340	980	(b)	547	890	(b)	732	632	628	(a)	746
Co	39.5	60.9	(a)	14	30	(b)	58.7	66.5	61.8	(a)	56
Ni	690	1160	(a)	250	540	(b)	1150	1390	1200	(a)	1167
Cu				3.8	5.9	(b)					
Zn				2	3.1	(b)			0.292	3.68	(c)
Ga	3.8		(a)	2.3	3.1	(b)			15.9	4190	(c)
Ge ppb											
As									0.022	0.43	(c)
Se											
Rb				2.4	4	(b)	3.6	9	2.5	(a)	0.111
Sr	197	166	(a)	130	140	(b)	193	206	206	(a)	5.96
Y	24	67	(a)	50	100	(b)					
Zr	90	292	(a)	200	330	(b)	90	70	75	(a)	
Nb	5	16	(a)	<10	<10	(b)					
Mo											
Ru											
Rh											
Pd ppb									4.25	86.1	(c)
Ag ppb									5.55	1.33	(c)
Cd ppb									1.45	9.76	(c)
In ppb									0.36	10.7	(c)
Sn ppb											
Sb ppb									1.24	11.8	(c)
Te ppb									11.2	146	(c)
Cs ppm					0.07	0.07	0.09	(a)	0.004	0.22	(c)
Ba	80	200	(a)	130	280	(b)	90	75	65	(a)	93
La	7.62	20.8	(a)	10	19	(b)	8	5.86	5.59	(a)	8.26
Ce	19.8	56.4	(a)			21.7	16	14.1	(a)	23	(a)
Pr											
Nd	14	34	(a)			13.7	9.5	9.2	(a)		
Sm	3.19	8.61	(a)			3.83	2.83	2.55	(a)		3.66
Eu	1.17	1.3	(a)			0.956	0.899	0.9	(a)		0.96
Gd		11	(a)								
Tb	0.63	1.87	(a)			0.8	0.55	0.574	(a)		0.82
Dy	4.25	11.3	(a)								
Ho	0.91	2.76	(a)								
Er											
Tm											
Yb	2.4	6.52	(a)			2.53	1.89	1.72	(a)		2.39
Lu	0.32	0.89	(a)			0.394	0.3	0.285	(a)		0.33
Hf	2.4	6.78	(a)			2.95	2.2	2.05	(a)		2.59
Ta	0.26	0.86	(a)			0.38	0.3	0.21	(a)		0.36
W ppb									0.028	5.18	(c)
Re ppb									0.126	45.7	(c)
Os ppb											
Ir ppb	13	29	(a)			30	36	39	(a)	0.216	42.8
Pt ppb											
Au ppb	14	20	(a)					13	(a)	0.324	29.1
Th ppm	0.73	2.55	(a)			1.5	1.26	0.91	(a)		1.93
U ppm	0.23	0.68	(a)			0.27	0.23	0.2	(a)	0.021	1.2
technique: (a) INAA, (b) mixed, (c) RNAA											

Table 1b. Chemical composition of 61015 anorthosites.

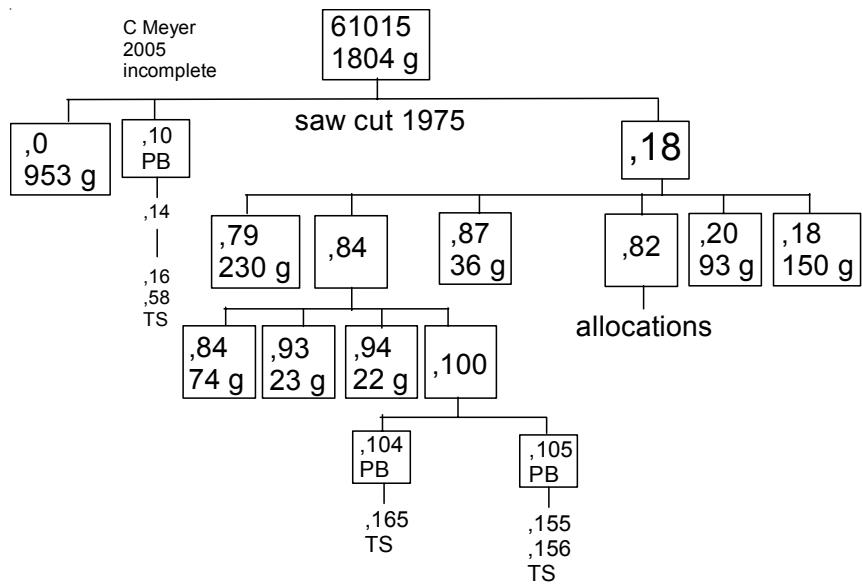
reference weight	James et al. 1984 (b)							ave. anor. to plot
SiO ₂ %								
TiO ₂	0.23		0.09	0.06			0.07	(a)
Al ₂ O ₃	31.2	33.5	34.3	32.5	32.8	34.7	32.5	(a)
FeO	2.96	0.233	0.765	0.881	0.789	0.539	2.12	(a)
MnO								
MgO	3.72	0.36	0.74	1.36	0.67	0.66	1.9	(a)
CaO	16.9	18.8	18.5	18.6	18	18.5	18.1	(a)
Na ₂ O	0.426	0.458	0.436	0.429	0.412	0.429	0.41	(a)
K ₂ O								
P ₂ O ₅								
S %								
sum								
Sc ppm	3.32	0.322	1.545	1.645	1.495	1.065	5.13	(a)
V								
Cr	290	4.46	102	79.5	64.1	46	3.44	(a)
Co	36	0.345	1.2	2.01	1.09	0.762	2.83	(a)
Ni	565	3	7	14	7	6	12	(a)
Cu								
Zn								
Ga								
Ge ppb								
As								
Se								
Rb								
Sr	277	225	218	216	210	220	206	(a)
Y								
Zr								
Nb								
Mo								
Ru								
Rh								
Pd ppb								
Ag ppb								
Cd ppb								
In ppb								
Sn ppb								
Sb ppb								
Te ppb								
Cs ppm								
Ba	77	11	17	17	13	13	11	(a)
La	6.54	0.294	0.785	0.733	0.368	0.543	0.647	(a) 0.56
Ce	18.3	0.67	1.8	1.7	1.02	1.33	1.36	(a) 1.3
Pr								
Nd								
Sm	3.12	0.088	0.313	0.294	0.125	0.149	0.151	(a) 0.19
Eu	1.11	1.04	1.02	1	0.99	1.03	0.98	(a) 1.01
Gd								
Tb	0.647	0.144	0.072	0.068	0.026	0.035	0.043	(a) 0.065
Dy								
Ho								
Er								
Tm								
Yb	2.04	0.0278	0.212	0.205	0.096	0.095	0.188	(a) 0.14
Lu	0.307	0.0033	0.034	0.036	0.0162	0.0144	0.039	(a) 0.024
Hf	2.36	0.006	0.19	0.15	0.05	0.06	0.06	(a)
Ta	0.32	0.002	0.021	0.014	0.004	0.008	0.015	(a)
W ppb								
Re ppb								
Os ppb								
Ir ppb								
Pt ppb								
Au ppb								
Th ppm	1.03		0.064	0.057	0.008	0.016	0.02	(a)
U ppm	0.22		0.043	0.038		0.025	0.03	(a)

technique: (a) INAA, (b) contaminated with matrix

Table 1c. Chemical composition of 61015 melt rock.

reference	James et al. 1984							av. VHA
weight	64.7	mg	112.3	124.6	100.5	71.5	31.8	2.18
SiO ₂ %								
TiO ₂	0.96		0.98	0.89	0.94	1	0.94	0.99
Al ₂ O ₃	20.5		24.1	21.1	20.5	21.3	21.9	28.1
FeO	8.94		8.57	6.9	7.93	7.98	6.89	7.79
MnO	0.09		0.1	0.09	0.09	0.1	0.09	0.08
MgO	12.8		13	12.7	12	12.5	12.7	10.6
CaO	11.6		13.3	12	11.9	11.7	11.6	15.5
Na ₂ O	0.455		0.5	0.464	0.44	0.459	0.475	0.515
K ₂ O						0.06	0.2	0.16
P ₂ O ₅								(a) 0.1
S %								
sum								
Sc ppm	10.8		11.6	10.8	10.8	11.6	11.2	9.53
V	25		31	32	28	29	27	32
Cr	1092		1150	1108	1094	1100	1070	974
Co	88		65	23	53	49	23	90
Ni	1420		1040	342	860	750	330	1420
Cu								
Zn								
Ga								
Ge ppb								
As								
Se								
Rb	5		10	7	7	7	9	16
Sr	211		240	164	227	168	178	190
Y								(a)
Zr	300		280	290	290	350	340	280
Nb								
Mo								
Ru								
Rh								
Pd ppb								
Ag ppb								
Cd ppb								
In ppb								
Sn ppb								
Sb ppb								
Te ppb								
Cs ppm	0.18		0.28	0.22	0.28	0.28	0.27	0.22
Ba	290		310	290	290	270	260	240
La	27.4		28.6	26.9	27.4	28.9	27.1	25.3
Ce	75.7		78.8	75.2	75.8	74.2	74	69.4
Pr								
Nd	46.2		48.2	45.9	46.9	48.4	48.9	42
Sm	13.01		13.63	12.86	12.91	12.87	12.53	11.54
Eu	1.47		1.61	1.48	1.48	1.49	1.5	1.46
Gd								
Tb	2.72		2.88	2.74	2.69	2.96	2.71	2.3
Dy								
Ho								
Er								
Tm								
Yb	8.68		9.15	8.65	8.73	8.75	8.5	7.18
Lu	1.3		1.35	1.29	1.31	1.38	1.31	1.14
Hf	10.05		10.45	9.98	10.1	10.4	10.1	8.2
Ta	1.35		1.35	1.27	1.32	1.13	1.09	0.87
W ppb								
Re ppb								
Os ppb								
Ir ppb	30		17	5.2	17	19	6.6	31
Pt ppb								
Au ppb						11	5.7	24
Th ppm	4.84		4.65	4.54	4.71	4.7	4.4	(a)
U ppm	0.95		1.16	1.03	1.1	1.17	1.23	0.9

technique: (a) INAA



Processing

61015 was sawn once (but was not slabbed) and was studied by the “James Consortium”. In 2005, it was used to prepare a public display for the Astronaut Ambassador Program.